Monthly Report No. 2

HYDROGEN-OXYGEN APS ENGINES

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Monthly Report No. 2

TABLE OF CONTENTS

TABLE LIST

FIGURE LIST

Monthly Report No. 2

I. PROGRAM OBJECTIVES

The primary objective of this contract is to generate a comprehensive technology base for high performance gaseous hydrogen-gaseous oxygen rocket engines suitable for APS. Durability requirements include injector and thrust chamber designs capable of 50 hours of firing life over a 10-year period with up to 10^6 pulses and single firings up to 1000 sec. The technical objectives will be accomplished and reported on in a twenty-one task program summarized below. The first ten tasks relate to high pressure APS engines; tasks eleven through twenty relate to low pressure APS engines and task twenty-one is a common reporting task.

Exhibit "A" Task	Task Titles for High Pressure APS Engines
I	Injector analysis and design
II	Injector fabrication
III	Thrust chamber analysis and design
IV	Thrust chamber fabrication
V	Ignition system analysis and design
VI	Ignition system fab and checkout
VII	Propellant valves preparation
VIII	Injector tests
IX	Thrust chamber cooling tests
X	Pulsing tests

Exhibit "A" Task	Task Titles for Low Pressure APS Engines
XI	Injector analysis and design
XII	Injector fabrication
XIII	Thrust chamber analysis and design
XIV	Thrust chamber fabrication
XV	Ignition system analysis and design
XVI	Ignition system fab and checkout
XVII	Propellant valves preparation
XVIII	Injector tests
XIX	Thrust chamber cooling tests
XX	Pulsing tests

	Common Task
XXI	Reporting requirements

I, Program Objectives (cont.)

Section II of this report covers the second month of activity of the high pressure engine technology portion of this contract. The first month of low pressure activities is covered in Section III. Section IV contains the total program progress and fiscal reports.

II. HIGH PRESSURE ENGINE TECHNOLOGY

A. PROGRAM PROGRESS

1. Task I - Injector Analysis and Design

Design of a coaxial element injector, initiated in mid-July, continued through August. The analysis and design focuses on two relatively independent areas. One is the configuration of the injector body which contains the propellant manifolds, thrust take-out brackets and flanges for thrust chamber and propellant feed attachments, and, of course, provisions for propellant injection elements. Optimization of the element configuration which will be incorporated in the injector body is the second area which is being investigated. The final element configuration will evolve from data obtained from a series of single element cold flow tests which were completed this past month.

a. Injector Body Design

The injector body has been designed such that either a bolted or welded assembly procedure can be employed (Figure II-1). The initial body has the oxidizer and fuel manifold cover bolted in position and therefore allows access to critical flow control and distribution areas. This first unit also serves as a cold flow model for the propellant manifolds. The need for flow distributing devices will be established in manifold cold flow tests. Design activities (hydraulic, structural, and engineering drawings) are now complete and materials sufficient to

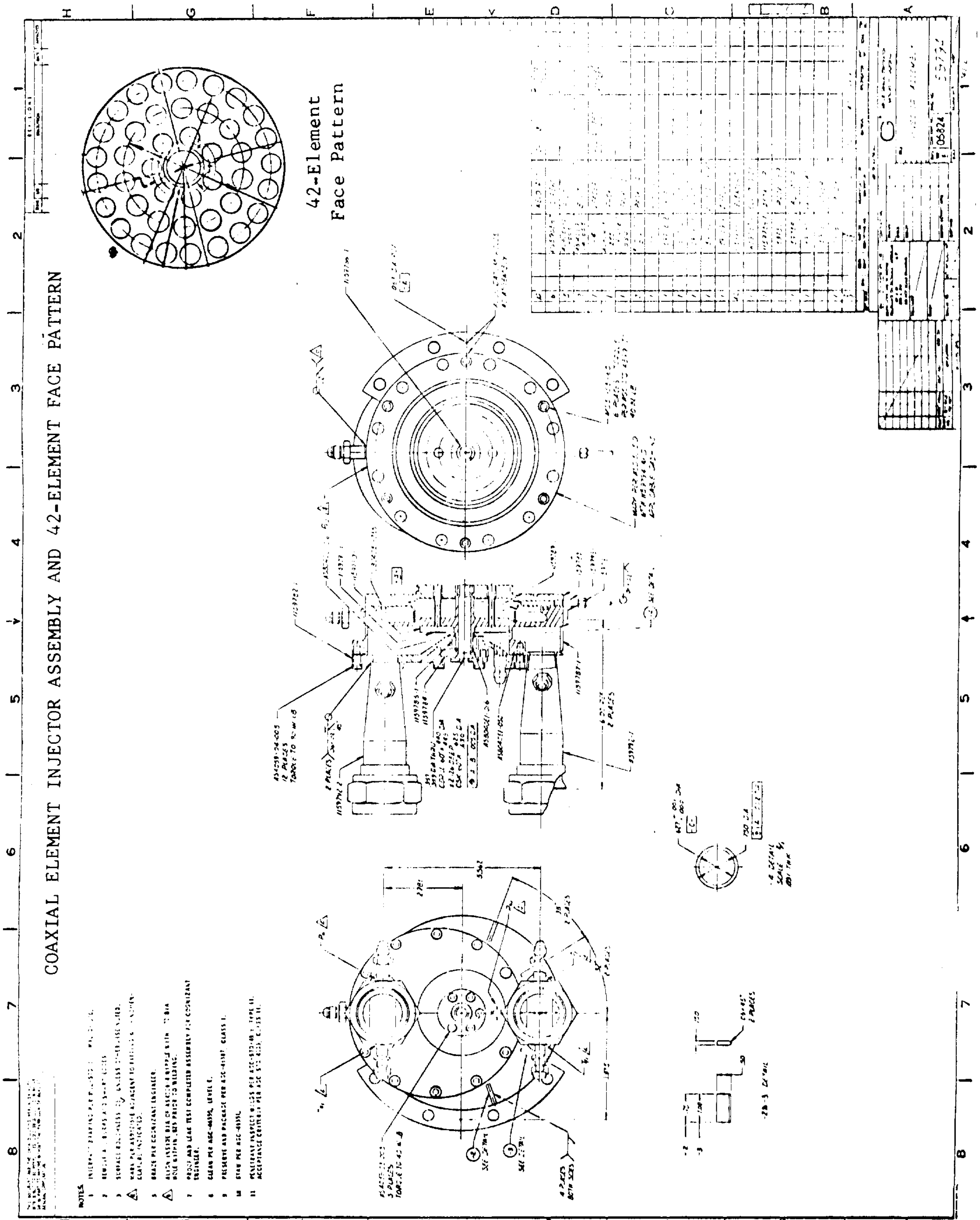

COAXIAL ELEMENT INJECTOR ASSEMBLY AND 42-ELEMENT FACE PATTERN
42-Element Face Pattern

Figure II-1

II, A, Program Progress (cont.)

fabricate up to four injector bodies have been ordered. The material selected for the injector body is 304L because of its excellent joining properties to itself by electron beam welding or brazing and to nickel elements by brazing.

b. Injector Face Design

The above body has been designed to incorporate a variety of cooled face plates as follows:

Face Cooling Concept	Material Form	Material Type
Transpiration cooling	Etched plates, Rigimesh	Stainless steel or Ni
Film cooling	Thin plate	Ni or Cu
Conduction/convection cooling	Thick plate	Cu or Cu alloys

Transpiration cooled face plates employing sintered porous materials such as Rigimesh are not being considered at this time because: (1) the structural and hydraulic characteristics of these sintered materials are not well defined and have been found to vary considerably from specimen to specimen; (2) porous filter material of this type could become plugged with contaminants over a period of time, thus reducing the face cooling; and (3) this type of cooling may not be required.

The cooling scheme currently under investigation employs the high velocity fuel in the annulus of each coaxial element in conjunction with a high thermal conductivity material to conduction/convection cool the face. Details of this analysis and preliminary results are presented later in this section.

Since one of the main program objectives for APS injector design is to investigate and develop the technology associated with a capability of 10^6 engine restarts, the current design studies go beyond the usual face cooling analyses. The face of the injector is anticipated to control its useful life since local face

II, A, Program Progress (cont.)

thermal stresses resulting from cyclic heating must be superimposed upon the local pressure induced cyclic loading generally experienced throughout the injector.

Activities during the past month have been directed toward identifying the major variables associated with the cycle life of the injector face and providing analyses from which face cooling concepts can be selected.

The severity of face thermal stresses are a function of (1) pulse width, (2) material properties, (3) geometry, (4) face heat flux, and (5) cooling method. For most designs, face thermal stresses can be expected to increase with pulse duration until steady-state thermal conditions are achieved. Typical thruster life cycle analyes, based on an APS usage defined by the Space Station Logistics Mission (Ref 1), are as follows:

10^6 short pulses, 20 to 40 μsec

2500 long burning, greater than 1.0 sec

A need for pulses greater than 40 μsec but less than 1.0 sec is not identified. These initial mission analyses suggest that thermal cycling could be much less severe than anticipated and engine efficiency in pulse mode operation much more important.

Design Factors

Equations 1 and 2 (Table II-1) define the variables which control the injector face thermal gradients, thermal stresses, and ultimate cycle life of a conductively/convectively cooled injector face. Equation 1 provides an approximate solution to the face temperature gradient for a circular plate of thickness (t) containing (N_e) uniformly spaced holes where the plate is exposed to a

Ref 1. NASA Space Shuttle Vehicle Description and Requirements Document, July 1970 Ed.

TABLE II-1

EQUATIONS FOR CALCULATING MAXIMUM AND ALLOWABLE COAXIAL ELEMENT FACE TEMPERATURE GRADIENT

$$\text{Maximum } \Delta T = \frac{Q}{K\sqrt{A} \quad \text{Tanh} \sqrt{A} \quad t} \qquad \text{Eq 1}$$

$$\text{Where} \quad A = \frac{2r_i \; h/K}{r_o^2 - r_i^2 + 2r_i \frac{h}{K}\left[\frac{r_o^2}{2} \ln \frac{r_o}{r_i} - \frac{1}{4}(r_o^2 - r_i^2)\right]}$$

$$r_o \approx \frac{r_f}{\sqrt{N_e}}$$

$$\text{Allowable } \Delta T = \frac{2(1 - u)(F_F - \sigma)}{\alpha E} \qquad \text{Eq 2}$$

h = Convective heat transfer coefficient in fuel annulus, Btu/sec-in.^{2}-^{o}F

K = Face plate thermal conductivity, Btu/sec-in.-^{o}F

N_e = Number of coaxial elements

r_i = Radius of fuel annulus in face plate, in.

r_f = Radius of injector face, in.

Q = Face heat flux, Btu/sec-in.^{2}

t = H_2 cooled face plate thickness, in.

ΔT = Maximum face temperature - injector body or propellant temperature

E = Elastic modulus, lb/in.^{2}

F_F = Fatigue strength for specific number of cycles at temperature, lb/in.^{2}

α = Coefficient of thermal expansion, in./in.-^{o}F

u = Poisson's ratio

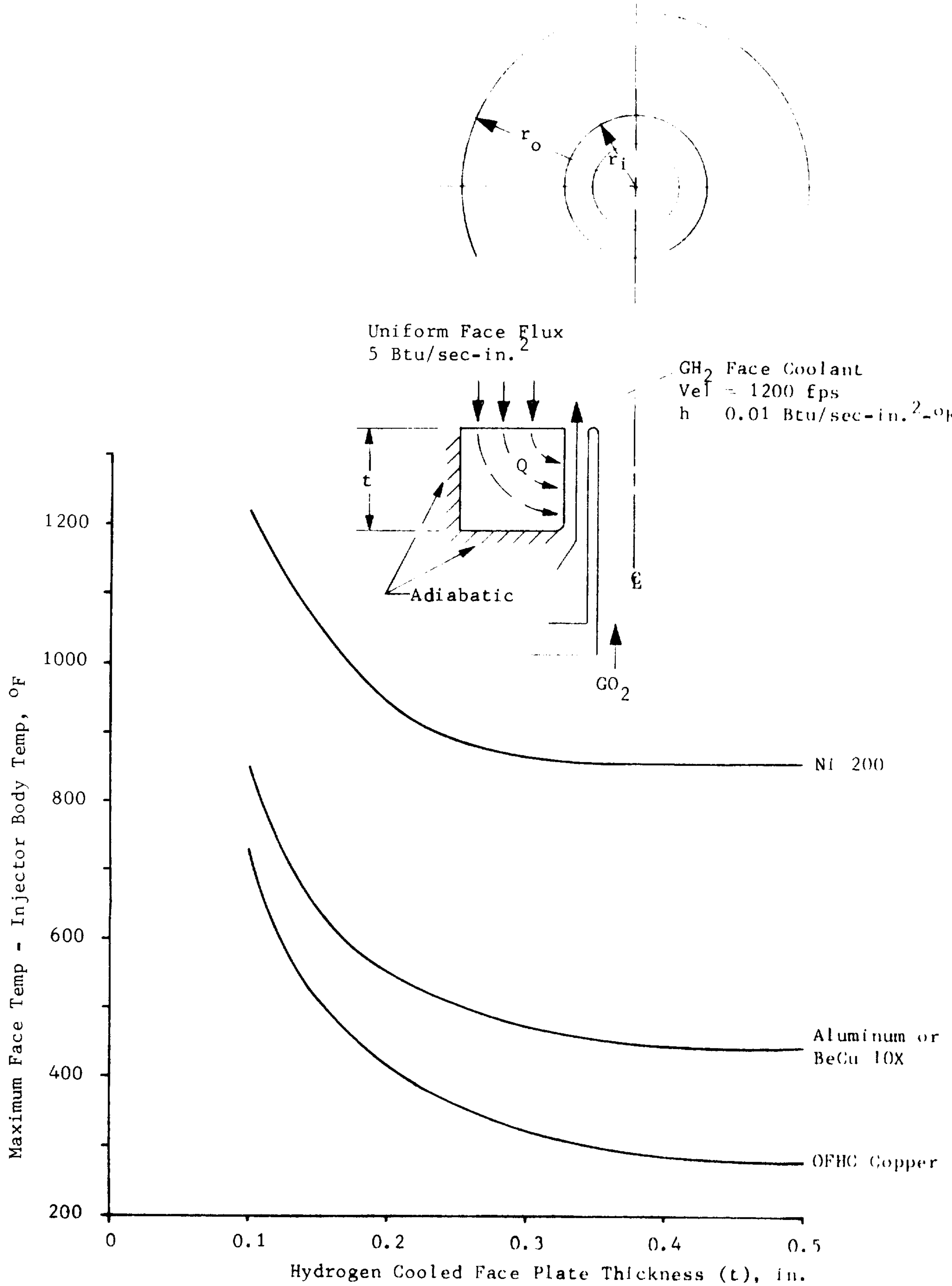
σ = Hydraulically induced stresses, lb/in.^{2}

II, A, Program Progress (cont.)

known flux on one face and is cooled by a convective coefficient (h) on the surface generated by the periphery of each hole and plate thickness. The temperature gradient (ΔT) which results is the difference between the local temperature at the heated face, most remote from the cooled holes, and the injector flange which is assumed to be at the propellant inlet temperature. Equation 2 provides an approximation of the structurally allowable temperature gradient when it is assumed that the point on the face which reaches a maximum temperature is fully restrained from thermal expansion.

Application of Equation 1 to the selected 42-element design pattern (insert Figure II-1) provides an estimate of the face temperature gradient as a function of face plate material and thickness as shown in Figure II-2. In this figure, the convective face flux is assumed to be 50% of the theoretical combustion chamber heat flux as calculated from the theoretical combustion temperature and the simplified Bartz convective heat transfer correlation. The face temperature gradient is observed to decrease both as the thermal conductivity of the face plate material increases and as the cooling surface (plate thickness) is increased. The benefits of increased thickness diminish rapidly, however, after thicknesses of about 0.25 in.

A conservative selection of face plate material and thickness has been made for the initial design which will be employed to obtain experimental injector face heat flux data. Since face plates are interchangeable, less conservative designs can be incorporated once more specific thermal test data become available. The first injector to be fabricated will incorporate a 0.5-in.-thick OFHC copper face plate instrumented with six gas-side thermocouples to obtain face temperature and heat fluxes. The maximum face temperature is currently estimated to be about 280°F higher than the fuel temperature. A major factor in selecting a 0.5-in. thickness is to accommodate the still undefined optimum oxidizer element recess which will reduce the effective fuel-cooled surface. Injector face temperatures can be expected to increase about 100°F per 0.1 in. of recess for recesses up to about 0.2 in.,



r_o
r_i
Uniform Face Flux
5 Btu/sec-in.^{2}
GH_2 Face Coolant
Vel = 1200 fps
h 0.01 Btu/sec-in.^{2}-°F
t
Q
Adiabatic
℄
GO_2
Maximum Face Temp - Injector Body Temp, °F
1200
1000
800
600
400
200
0
0.1
0.2
0.3
0.4
0.5
Hydrogen Cooled Face Plate Thickness (t), in.
Ni 200
Aluminum or
BeCu 10X
OFHC Copper

Figure II-2

II, A, Program Progress (cont.)

assuming there is no additional heat input resulting from combustion within the recessed area of the element. The degree of premixing resulting from recess of the oxidizer port is discussed in a later paragraph.

The lower part of Figure II-3, derived from Equation 1, demonstrates the influence of the number of elements and face plate thickness for a 0.002 Btu/sec-in.-^{o}F material conductivity which corresponds to either T-6063 aluminum or BeCu 10X. In terms of injector face cooling, little advantage is realized in increasing the number of elements beyond about 40 or fuel-cooled face thickness 0.25 in. greater than oxidizer tube recess. Beryllium copper or aluminum alloy face plates would be expected to operate approximately 500^{o}F higher than the fuel inlet temperature and could be considered as superior replacements for OFHC copper as suggested in the upper part of Figure II-3, which combines thermal and structural considerations of Equations 1 and 2.

The upper half of Figure II-3 indicates the maximum face heat flux various materials can withstand as a function of the number of thermal cycles. The superiority of BeCu 10X and aluminum alloy T-6061 over nickel and OFHC copper are evident. A significant limitation of aluminum, however, is that it loses strength rapidly at temperatures above 400^{o}F and its durability could be substantially reduced if propellant temperatures higher than ambient are sustained for any duration.

Final decisions on the next generation of face plate materials will await optimization of the element recess and experimental thermal results on the OFHC copper designs.

c. Injector Element Configuration

The final and most important aspect of the injector design is optimization of the coaxial elements. Element optimization is accomplished in a series of cold flow tests using the apparatus shown in Figure II-4 in which heated

THERMAL AND LIFE CYCLE CHARACTERISTICS OF
FACE PLATES FOR COAXIAL ELEMENT INJECTORS

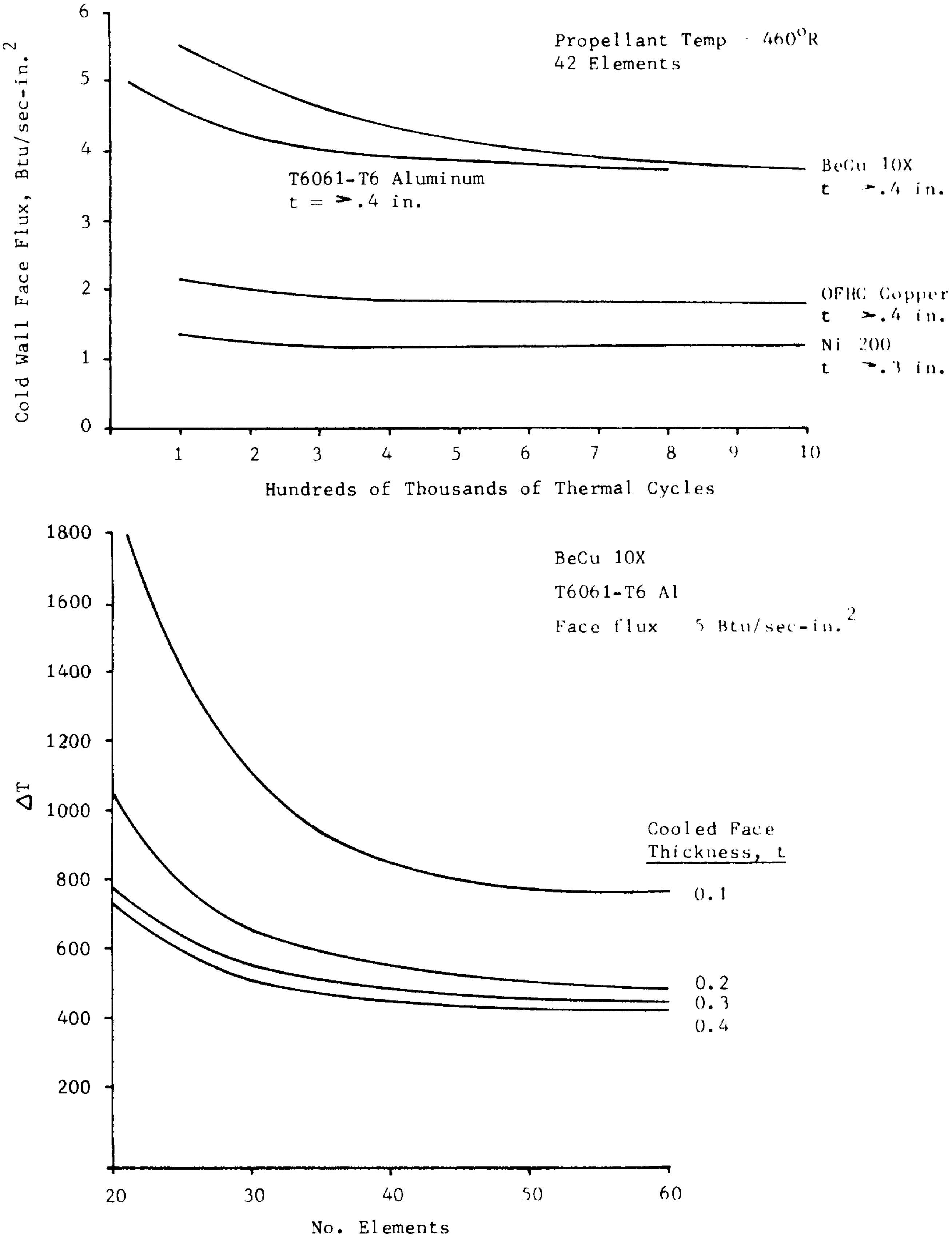


Figure 11-3

II, A, Program Progress (cont.)

helium was used to simulate hydrogen and cooled nitrogen employed to simulate oxygen. Tests were conducted on one of 42 full-scale elements.

Number of elements	Full scale	42
Approximate spacing, in.	Full scale	0.45
Ox tube diameter at injection, in.		0.264
Fuel gap, in.		0.017
Ox injection velocity, fps		100
Fuel injection velocity, fps		1200

Respective propellant simulant temperatures and chamber pressures were adjusted to provide velocities and densities which correspond to hydrogen and oxygen under actual 300 psia operating conditions with ambient temperature propellants. Mach number and Reynolds number were also approximately simulated.

The objectives of element cold flow testing were:

(1) Establish element hydraulic characteristics.
(2) Establish element mixing characteristics.
(3) Establish element thermal characteristics.
(4) Establish element chamber wall compatibility and the need for special elements near the wall.

The parameters investigated were:

(1) Oxidizer Inlet Configuration

(a) Single orifice at element inlet
(b) Multiple (smaller) orifices at element inlet.
(c) Swirler at element inlet.

II, A, Program Progress (cont.)

(2) Propellant Premix Length

Recess = 0, 0.5, and 1.0X oxidizer tube diameter

(3) Operational Characteristics of Selected Configuration

(a) Variation of total propellant flow.

(b) Variation of element mixture ratio.

Two types of data were recorded for each element configuration investigated. Adiabatic wall temperature measurements on the outside of the fuel tube ($T_{0.0}$ to $T_{0.3}$, Figure II-4) reflect the mixing which takes place within the injection orifice as the amount of premix or oxidizer tube recess is increased. At the same time, static and total pressure rakes or total temperature rakes located downstream of the injection plane record gas pressure and temperature profiles from which mixing efficiency, mass flux, and mixture ratio distribution profiles can be calculated.

Coaxial element cold flow experiments were completed during this second contract month. In total, 95 pressure rake and 57 temperature rake surveys were obtained. Cup premix data were obtained on all 152 tests. Test variables included three types of oxidizer flow control orifices, one of which hydraulically produced swirl flow of the gaseous oxidizer. Oxidizer tube recesses of 0.0, 0.12, and 0.25 in. were evaluated with nonswirl inlets and recesses of 0.0 and 0.12 in. with swirl inlets. Additional tests with element tips scarfed at 22° and 45° were conducted with the swirl oxidizer inlet configurations. Table II-2 provides a summary of the test conditions. Temperature and pressure rake data are in the process of being evaluated. Preliminary evaluation of adiabatic wall temperature data from the premix zone indicate a significant oxidizer penetration of the 0.017-in. annular fuel stream when premix lengths exceed about 0.1 in. The addition of oxidizer swirl is shown to increase the premix zone mixing measurably. The significance

SCHEMATIC DRAWING OF ELEMENT COLD FLOW TEST APPARATUS

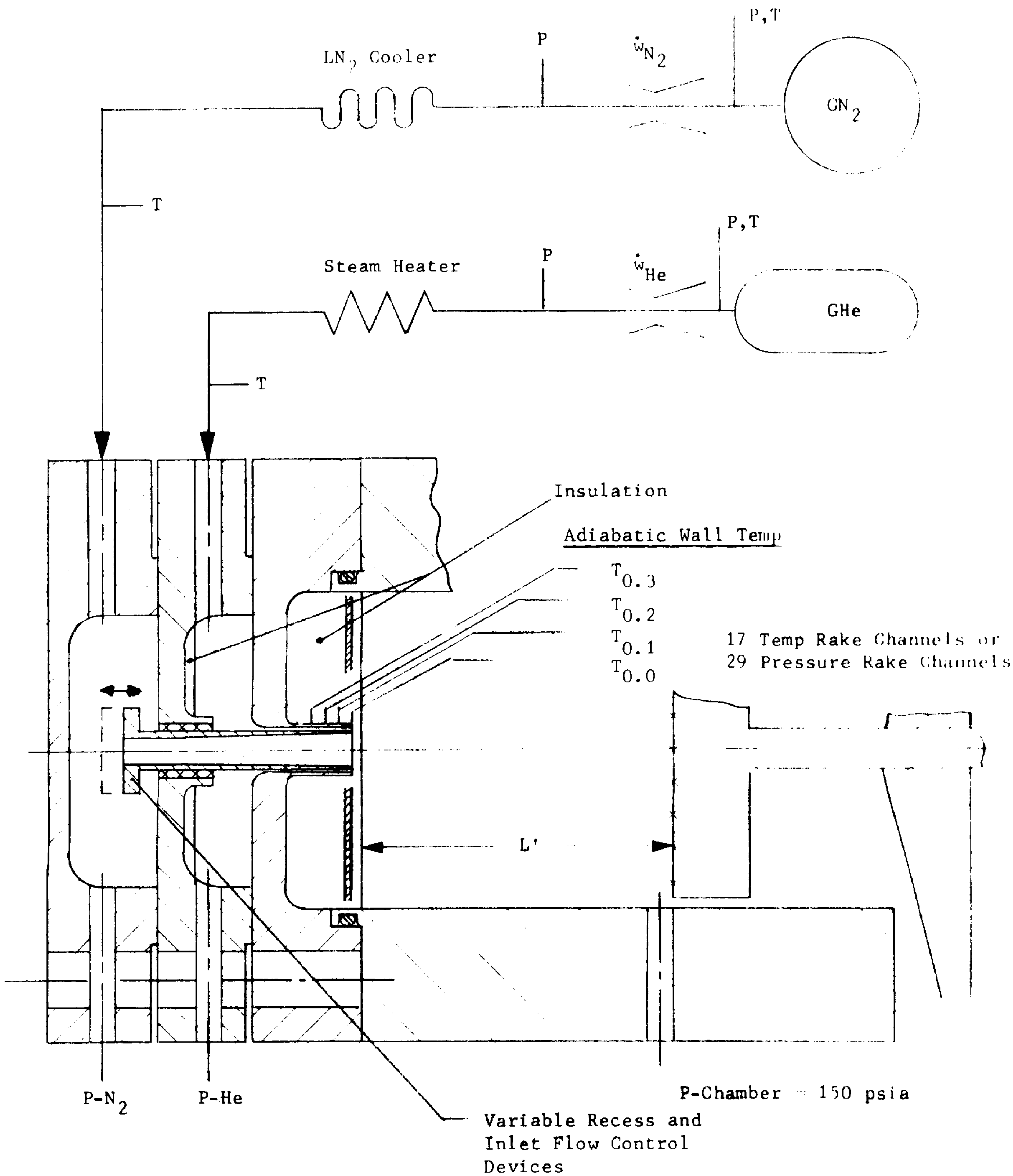


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Figure II-4

TABLE II-2

HiP_c - COAXIAL ELEMENT COLD FLOW TESTS

Date	Run No.	Rake Station (in.)	$\dot{w}_{N_2}$ (lb/sec)	$\dot{w}_{He}$ (lb/sec)	Oxidizer Inlet	Oxidizer Recess (in.)	Element Tip	Test Function
PRESSURE RAKE TESTS								
24-25 Aug	1-17	0,0.5,1,2,3	--	--	--	0-0.25	Normal	Flow system checkout
25 Aug	18-21	0,0.5,1,2,3	0.063	0.013	No orifice	0.25	Normal	Mass flux profiles (L)
25 Aug	22-25	0,0.5,2,3	0.063	0.013	No orifice	0	Normal	Mass flux profiles (L)
28 Aug	26-27	0,1	0.063	0	No orifice	0.12	Normal	Ox flow characteristics
28 Aug	29-34	0,0.5,2,3	0.063	0.013	No orifice	0.12	Normal	Mass flux profiles (L)
28 Aug	35-40	0.5	0.04-0.063	0.0077-0.021	No orifice	0.12	Normal	Velocity and mixture ratio effects
28 Aug	42-43	0,1,2	0.063	0	No orifice	0.12	Normal	
28 Aug	44-46	0,1,2	0.063	0	Single orifice	0.12	Normal	Effect of orifice on flow distribution
28 Aug	47-53	0,1,2	0.063	0	Six orifice	0.12	Normal	Same as above + 5 rotational positions
28 Aug	54-56	0,1,2	0.063	0	Swirler	0	Normal	Swirl characteristics
28 Aug	57-60	0,0.5,2,3	0.063	0.013	Swirler	0	Normal	Mass flux profiles (L)
31 Aug	61-65	0,0.5,2,3	0.063	0.013	Swirler	0.12	Normal	Mass flux profiles (L)
31 Aug	66-69	0.5	0.063	0.013	Swirler	0	Normal	Rotational survey(θ) Mass flux
31 Aug	70-75	0.5	0.04-0.063	0.0077-0.021	Swirler	0	Normal	Velocity and mixture ratio effects
31 Aug	76-79	0.5	0.063	0	Swirler	0	22° scarfed	Rotational mass flux profiles (θ)
31 Aug	80-83	0.5	0.063	0.013	Swirler	0	22° scarfed	
31 Aug	84-87	0.5	0.063	0	Swirler	0	-5° scarfed	
31 Aug	88-95	0.5	0.063	0.013	Swirler	0	-5° scarfed	

TABLE II-2 (cont.)

Date	Run No.	Rake Station (in.)	$\dot{w}_{N_2}$ (lb/sec)	$\dot{w}_{He}$ (lb/sec)	Oxidizer Inlet	Oxidizer Recess (in.)	Element Tip	Test Function
TEMPERATURE RAKE TESTS								
3 Sept	T1-T6	0	0.04-0.063	0.0077-0.021	No orifice	0	Normal	Temp calibration tests
3 Sept	T7-T9	0.5,2,3	0.063	0.013	No orifice	0	Normal	MR distribution (L)
3 Sept	T10-T13	0,0.5,2,3	0.063	0.013	No orifice	0.25	Normal	MR distribution (L)
3 Sept	T14-T17	1	0.063	0.013	No orifice	0.25	Normal	Rotational survey (θ)
3 Sept	T18-T21	0,0.5,2,3	0.063	0.013	No orifice	0.12	Normal	MR distribution (L)
3 Sept	T22-T27	0.5	0.04-0.063	0.0077-0.021	No orifice	0.12	Normal	Velocity and MR effects
3 Sept	T28-T31	0.5	0.063	0.013	Swirler	0	45° scarfed	Rotational survey (θ)
3 Sept	T32-T35	0,0.5,2,3	0.063	0.013	Swirler	0.12	Normal	MR distribution (L)
3 Sept	T36-T40	0,0.5,2,3	0.063	0.013	Swirler	0	Normal	MR distribution (L)
3 Sept	T41-T43	0.5	0.063	0.013	Swirler	0	Normal	Rotational survey (θ)
3 Sept	T44-T49	0.5	0.04-0.063	0.0077-0.021	Swirler	0	Normal	Velocity and MR effects
3 Sept	T50-T53	0,0.5,2,3	0.063	0.013	Single orifice	0.12	Normal	MR distribution (L)
3 Sept	T54-T57	0,0.5,2,3	0.063	0.013	Six orifice	0.12	Normal	MR distribution (L)

of excessive premixing is a loss of face cooling capability and a less durable design. Optimization of element recess to obtain good mixing and adequate face cooling and the potential use of swirlers to replace or reduce the amount of premixing required awaits completion of the pressure and temperature rake data reduction.

d. Impinging Coaxial Injectors

Aerojet designs for an impinging coaxial element injector have also been completed along with cold flow studies for several types of elements. The results of these element cold flow studies are shown in Figure II-5. An intermediate I Triplet element configuration has been selected to replace the triplet pattern employed on current designs. Figure II-5 demonstrates the new configuration to have a significantly higher mixing effectiveness over a wide range of propellant momentum ratios. Cold flow studies of the manifolding for this design indicates fuel flow distribution to be acceptable; however, oxidizer flow maldistributions of ±15% need to be corrected.

2. Task II - Injector Fabrication

Initiation of fabrication of the coaxial element injector body for manifold cold flow studies has been delayed about one week. Element cold flow test hardware shown schematically in Figure II-3, normal and scarfed elements, and orifice and swirl inlet adapters were completed in this report period.

3. Task III

No activity scheduled.

MIXING EFFICIENCY OF IMPINGING COAXIAL ELEMENTS FROM
SINGLE ELEMENT COLD FLOW STUDIES

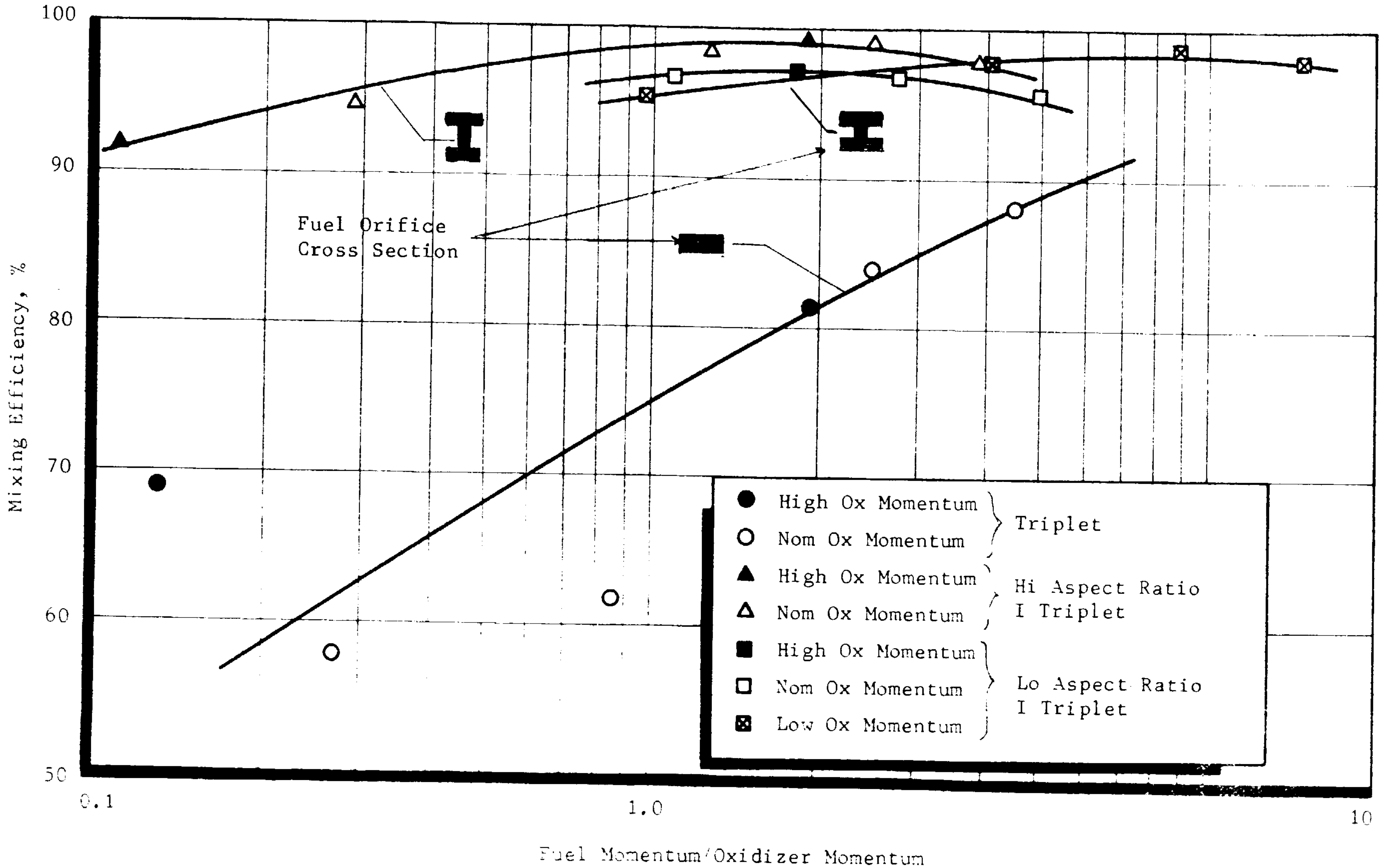


Figure II-5

II, A, Program Progress (cont.)

4. Task IV

No activity scheduled.

5. Task V - Ignition System Analysis and Designs

In the last report period, the thermal analysis of the spark igniter was updated to incorporate the experimental heat flux obtained from initial heat sink igniter tests. The initial test series consisted of short duration (0.1 sec) tests in a 0.05-in.-thick Hastelloy X chamber which had seven backside thermocouples located along the axis and around the periphery. The experimental data indicated that the heat flux calculated from the theoretical combustion temperature at nominal mixture ratio and the simplified Bartz correlation for local heat transfer coefficient was adequate for design. The updated analytical procedure using the experimental data was employed to design a new nickel igniter chamber having higher coolant velocities, higher core mixture ratios (50 vs 35), and lower hot gas flow rates. Analyses indicate maximum wall temperatures will be less than 1500°F. This is expected to be adequate for igniting all thrusters in the planned test program.

The design of a catalytic igniter has also been modified to incorporate the most recent thermal data and analyses.

6. Task VI - Igniter Checkout Tests

The second series of igniter checkout is waiting completion of fabrication of the nickel igniter chamber.

II, A, Program Progress (cont.)

7. Task VII - Propellant Valves Preparation

Drawings of the high response, low pressure drop valve assembly have been completed. The design incorporates a standard valve barrel assembly fabricated by Controls Components Inc. and an Aerojet design valve body and pneumatic actuator. Orders for valve parts have been placed and assembly and checkout is rescheduled for late September.

8. Task VIII - Injector Tests

One hundred fifty-two coaxial element cold flow tests, listed in Table II-2 and discussed in Section II,A,1, were completed.

9. Tasks IX and X

No activity scheduled.

B. CURRENT PROBLEMS

No significant technical or scheduling problems are foreseen at this time.

C. WORK TO BE PERFORMED IN NEXT REPORT PERIOD (BY TASK)

Task I

1. Complete cold flow data reduction and select optimum configuration for coaxial element from reduced data.
2. Perform additional cold flow studies on manifolding for impinging coaxial injector.

II, C, Work to be Performed in Next Report Period (by Task) (cont.)

Task II

Initiate fabrication of coaxial element injector body.

Task III

Initiate preliminary analyses of cooled chambers.

Task IV - No activity.

Tasks V and VI

Identify igniter operating characteristics from checkout tests for spark and catalytic igniters.

Task VII

Complete valve fabrication; initiate valve checkout tests.

Task VIII

Initiate injector checkout tests.

Tasks IX and X - No activity.

III. LOW PRESSURE TECHNOLOGY PROGRAM

A. PROGRAM PROGRESS (TASKS XI THROUGH XX)

1. Task XI - Injector Analysis and Design

The injector element types recommended to the NASA/LeRC project manager for this program were a coaxial and a radial vane design. The initial activity on this task was to re-evaluate the analyses which were used to select quantities and sizes of coaxial elements and vanes.

a. Coaxial Element Evaluation

The coaxial element configuration selected for this parametric evaluation uses a simple thin-wall oxidizer tube permanently brazed to the face and backing plates. Earlier studies were based on an element design which used a constant wall thickness (regardless of element size) oxygen tube to facilitate individual element replacement. The objective of the current study was to determine the effect of element quantities on element size and hydrogen manifold flow velocities prior to selecting the element size for flow testing.

Element quantities ranging from 50 to 1000 were evaluated assuming oxidizer and fuel injection velocities of 150 ft/sec and 1400 ft/sec, respectively. Comparisons of element size, chamber length required for mixing, hydrogen annulus width, and velocity of hydrogen in the fuel manifold were made for the range of element quantities. Also evaluated were fabrication simplicity and face cooling using candidate face materials.

Figure III-1 shows the effect of element quantity on hydrogen manifold velocity for a 3.5-in.-high manifold. It can be seen that the manifold velocity decreases somewhat with increasing quantities of elements but that significant manifold velocity decrease is not realized for more than 300 elements. This trend is primarily the result of the criterion used to select the oxygen tube wall thickness. For this evaluation, the wall thickness varied from 0.0125 in. for a 0.2-in.-dia tube to 0.0325 in. for a 1.0-in.-dia tube.

Figure III-2 shows the effect of element quantity on element dimensions. Here, it is shown that the fuel annulus width becomes somewhat small, 0.037 in. for 400 elements. A small hydrogen gap can result in flow variation due to tolerance effects. Element quantities beyond 400 do not result in significant oxidizer tube size reduction unless a very large element quantity is considered. With less than 100 elements, the oxidizer tubes become large, requiring a long chamber length or special element designs for complete mixing in a shorter chamber length. Small element quantities (below 100) make the face cooling more adverse because of large uncooled lengths between elements.

Figure III-3 compares element quantity (oxidizer tube diameter) with the chamber length required for three assumed element mixing efficiencies shown as L/D ratios. Presuming the validity of the L/D mixing length as a performance criterion, quantities of elements beyond 400 will not significantly reduce the required chamber length.

Flow tests of a coaxial element conducted in Task I using a 0.265-in.-dia oxygen tube have been completed and the data analysis is in process. These results, along with preproposal test data, will be used to define a performance criterion which will be applied to an 8-in.-long chamber, which is near the minimum practical length for this configuration.

To increase heat flow from the injector face to the fuel in the hydrogen annulus, the element to face plate interface has been designed with fuel in direct contact with the face. Previous designs considered used a fuel sleeve which was swaged into the injector face, restricting the heat flow from the face to the

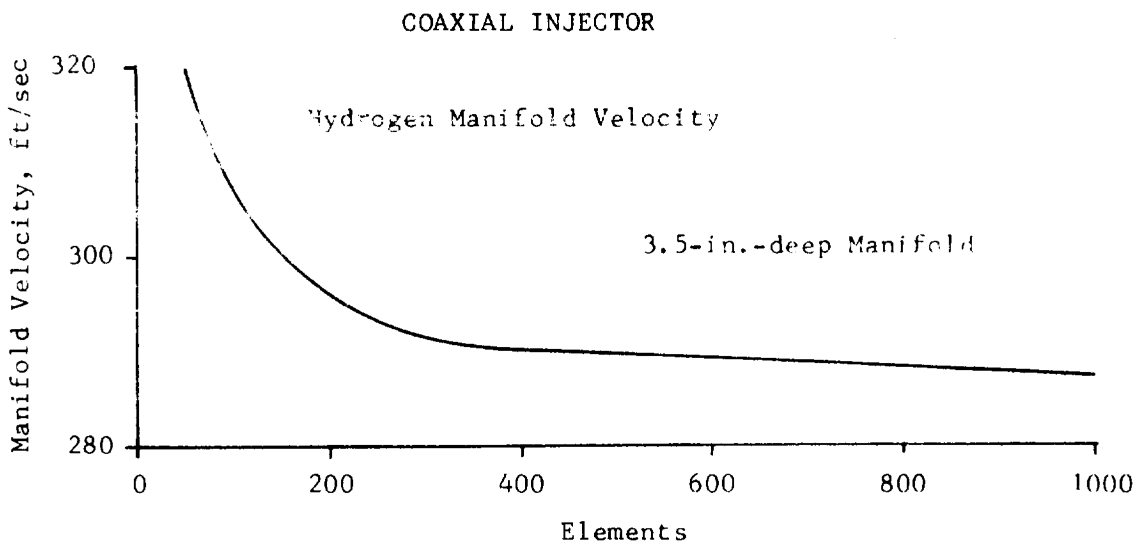


Figure III-1

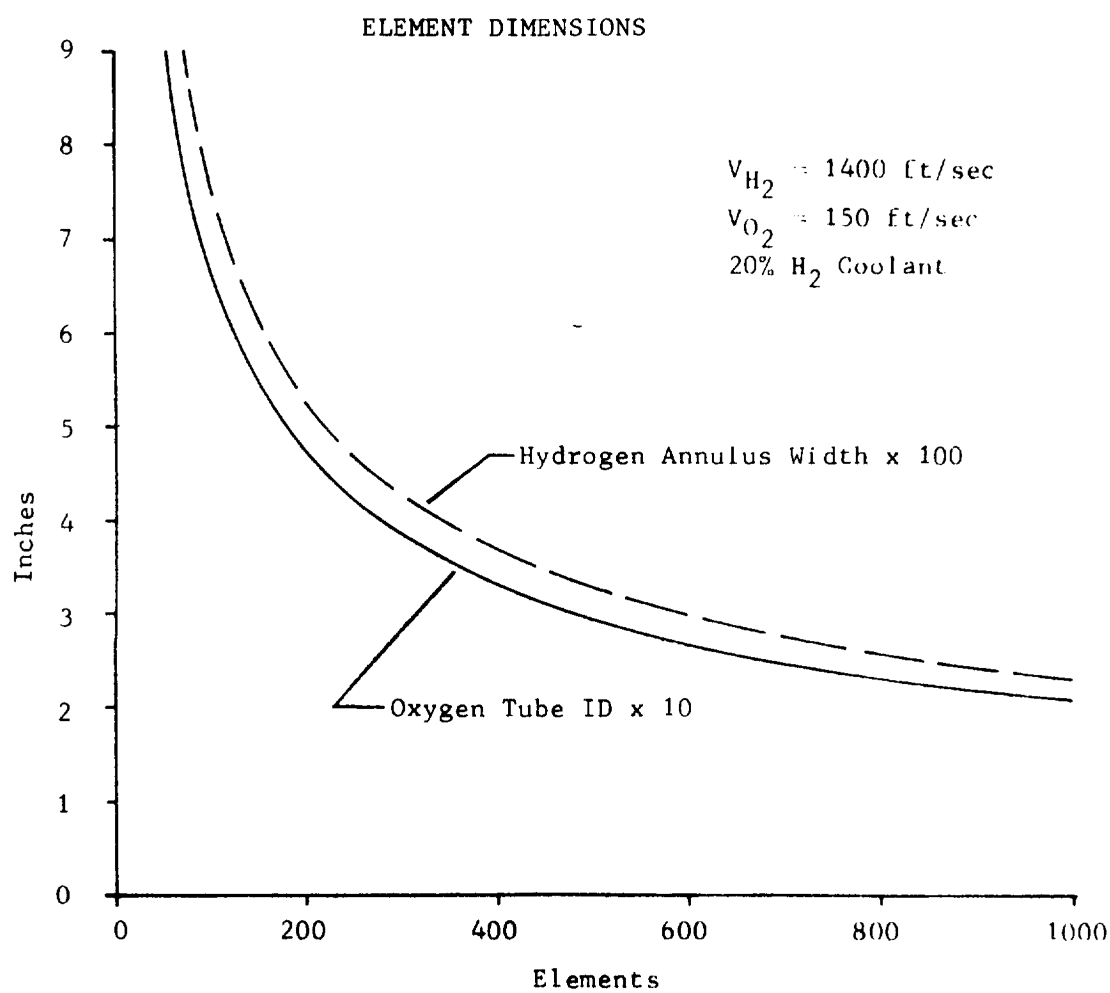


Figure III-2

EFFECT OF ELEMENT QUANTITY ON MIXING LENGTH

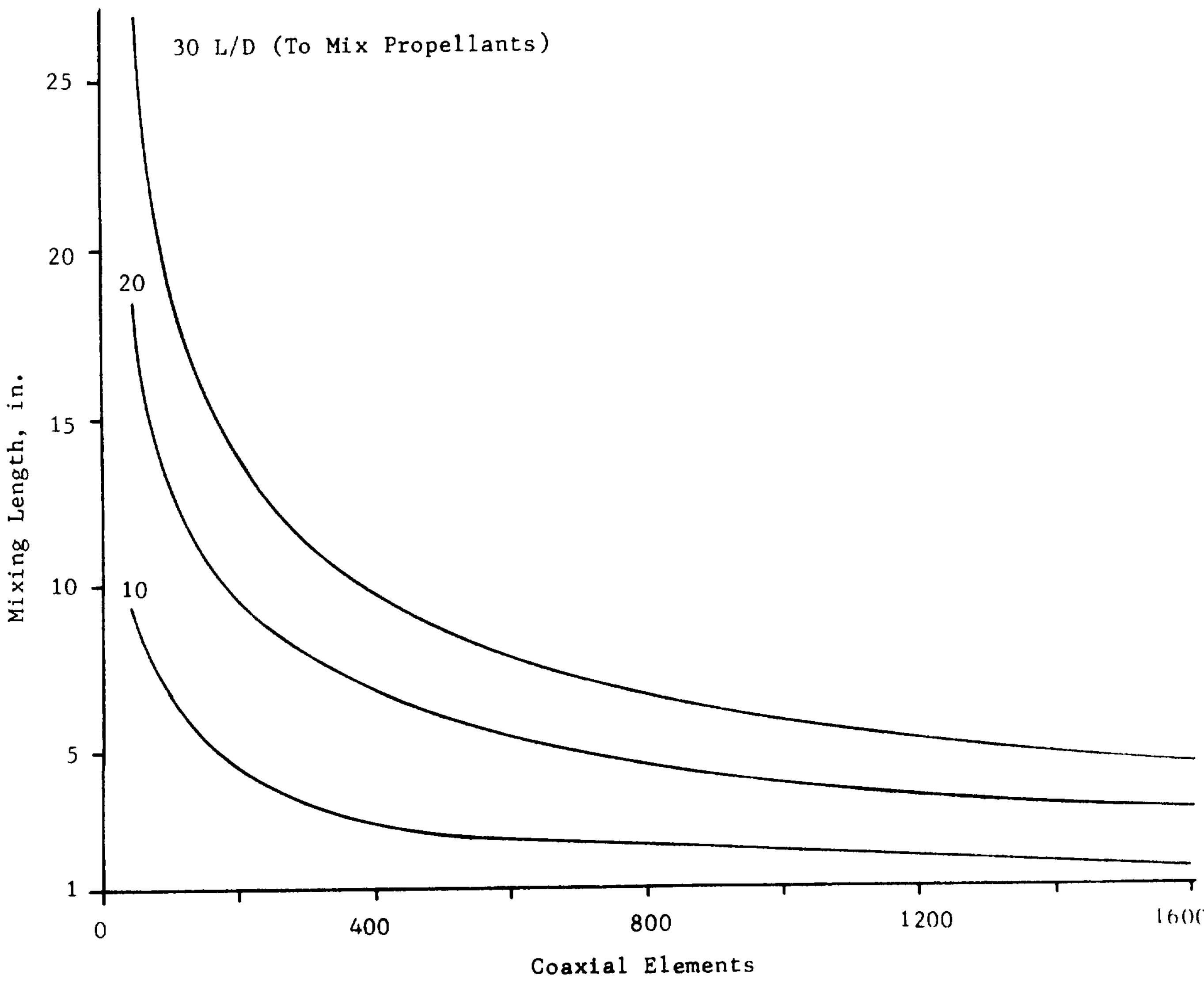


Figure III-3

III, A, Program Progress (Tasks XI Through XX) (cont.)

coolant as required by conductively cooled face designs. Figure III-4 shows the predicted steady-state temperature gradient between the uncooled portion of a conductively cooled face and the hydrogen outer annulus for three candidate materials. Although a better definition of the thermal environment is required for an exact analysis, the feasibility of using a conductively cooled face is indicated.

The recommended element design and fabrication steps are shown in Figure III-5. This element will be fabricated by match drilling the face plate and back plate as an assembly to reduce tolerance requirements. The face plate will be drilled with a two-diameter tool which will provide the required fuel annulus while ensuring concentricity. The smaller diameter portion of the face plate hole will then be broached to provide lands for centering and attaching the oxidizer tubes.

b. Vaned Element Evaluation

The parametric study conducted earlier was re-evaluated to establish vane quantity, height, and width for cold flow hardware design. The results are plotted in Figures III-6, III-7, and III-8. Design conditions used were:

- Low fuel manifold velocity - 200 ft/sec (critical due to the short orifice L/D).
- Maximum gap between vanes less than 0.25 in. to prevent flashback (0.36 is the minimum theoretical quench distance).
- Minimum gap between vanes not less than 0.100 in. (to minimize tolerance effects on oxidizer flow).
- Mixed velocity less than 700 ft/sec (Mach = 0.3) to minimize friction pressure drop between vanes and expansion loss at tip end.
- Mixed velocity above flame propogation velocity (about 250 ft/sec) to minimize flashback potential.
- Vane width less than 0.60 in. to limit the uncooled surface.
- Oxygen injection velocity approximately 100 to 150 ft/sec.

EFFECT OF MATERIAL TYPE AND THICKNESS ON STEADY-STATE INJECTOR FACE TEMPERATURE

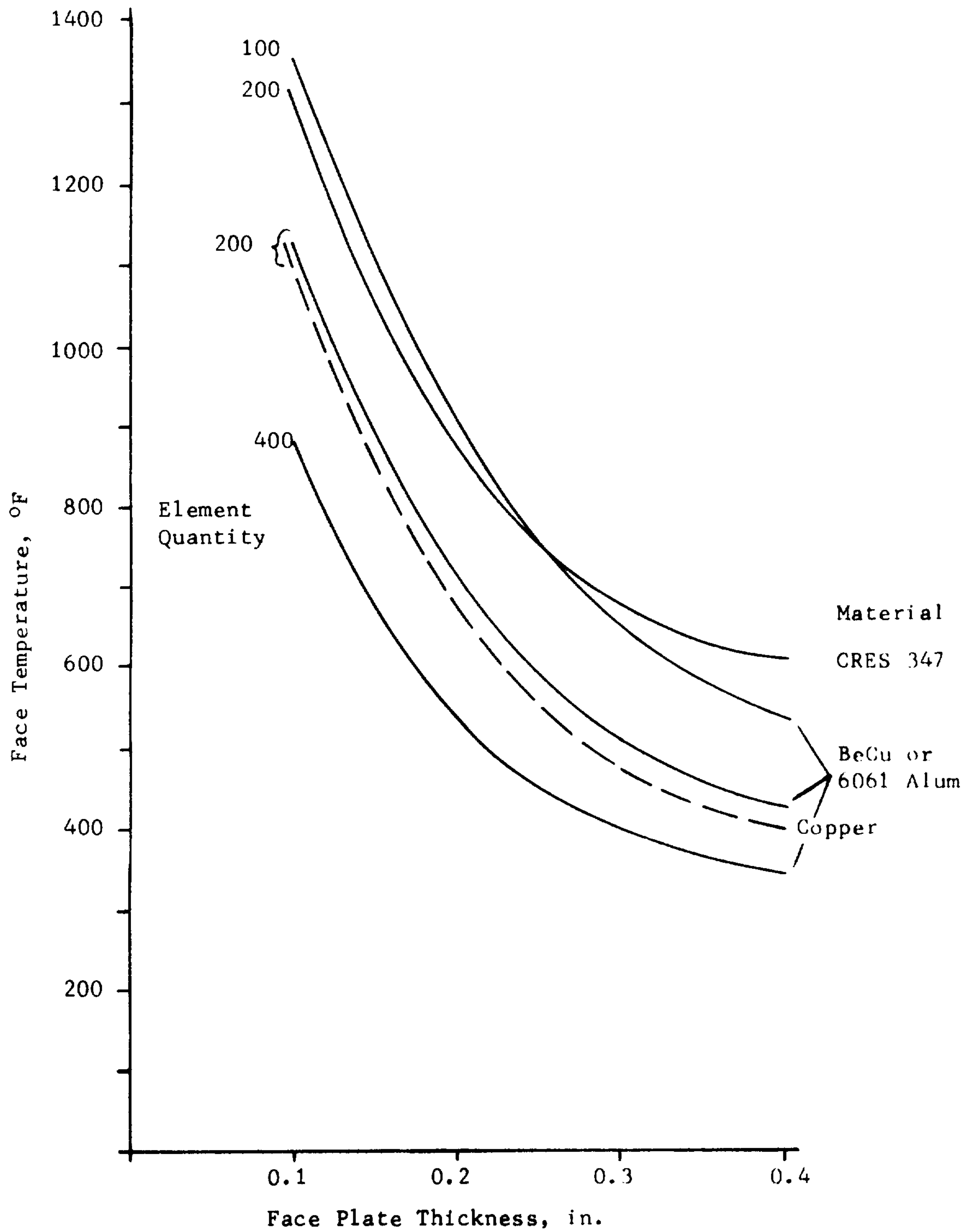
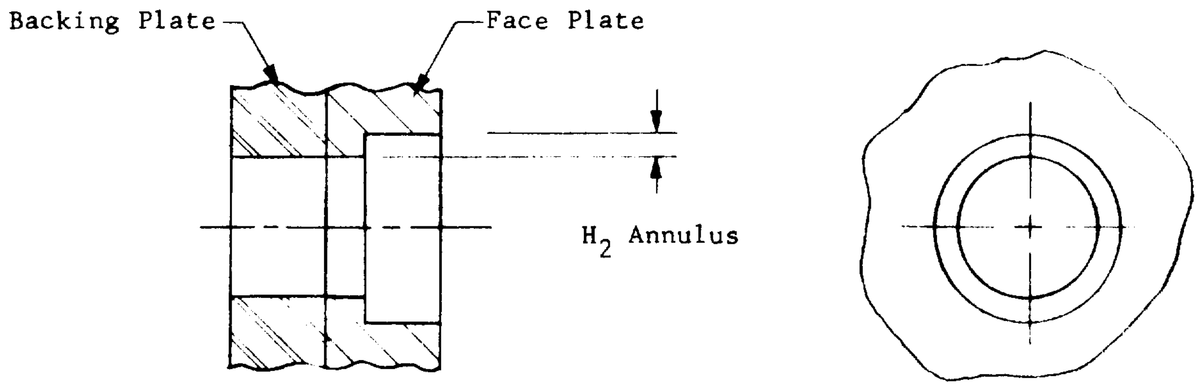
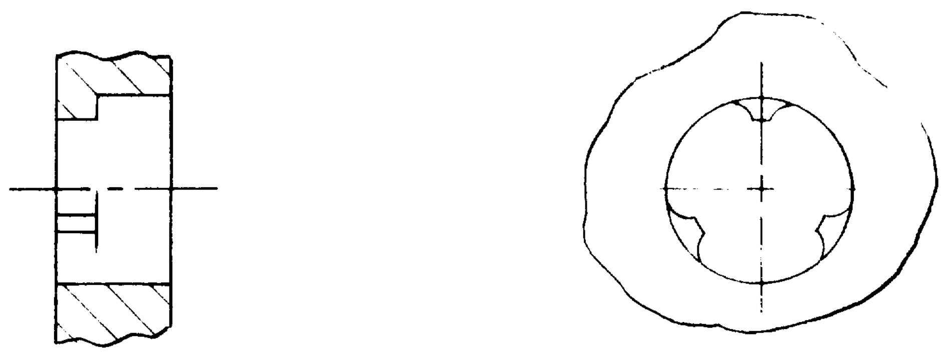


Figure III-4

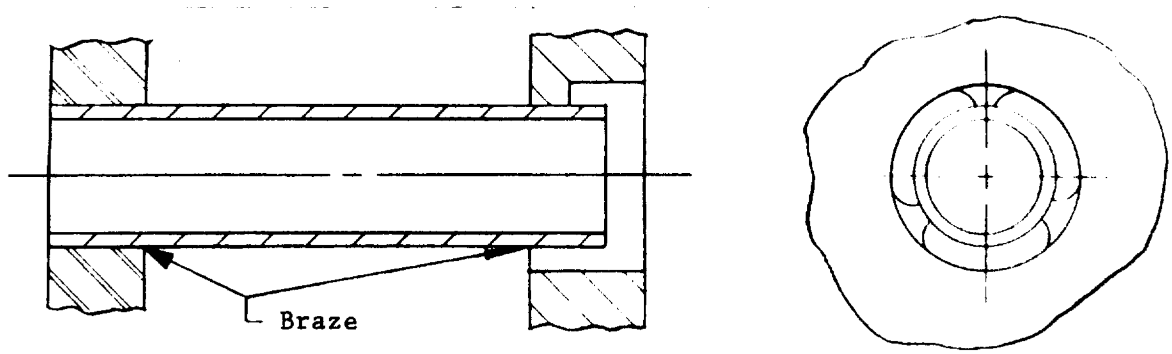
COAXIAL ELEMENT FABRICATION STEPS



Match Drilling



Broach Face Plate



Braze Oxygen Tubes

III, A, Program Progress (Tasks XI Through XX) (cont.)

The fuel vane width required for 200 ft/sec hydrogen velocity in the vane was calculated for vane heights in the range of interest (2.5 to 4.0 in.) and for varying vane quantities. These results, shown in Figure III-6, reveal that more vanes (a finer pattern) or smaller vanes (less uncooled surface) are possible with longer vanes (3.5 to 4.0 in.). Figure III-7 shows that the oxygen injection velocity increases quite rapidly with element quantity for the shorter vane heights. This is because, with the shorter vanes, nearly all of the injector face area is required for manifolding to maintain the hydrogen velocity of 200 ft/sec.

Having established a need for longer vanes, a 3.5-in. vane was selected since it also is the same as the plenum height for the coaxial assembly allowing element assemblies to be interchanged with common fuel and oxidizer manifolds.

Figure III-8 shows the oxygen flow gap or premix gap width for various vane quantities. In order to maintain the vane gap below 0.25 in., a vane quantity greater than 50 is required. Quantities in excess of 80 result in gap width at the OD of the vane of less than about 0.100 in., increasing the sensitivity of the assembly to tolerances. A sixty-vane design was selected.

c. Film Coolant Ring Design

Design of a film coolant ring assembly has been initiated and drafting is in process. The concept selected for this design uses a fuel manifold assembly with separate coolant sleeves which form an injection annulus with the chamber ID. The sleeve designs will either vary injection velocity for a fixed coolant quantity or they will maintain a fixed injection velocity with variations in coolant flow rate. Sleeve lengths will also be evaluated. The configuration combinations planned are three sleeve lengths (0, 2, and 4 in.) and three coolant flow rates of 10, 20, and 30%.

EFFECT OF VANE QUANTITY AND HEIGHT ON FUEL VANE WIDTH

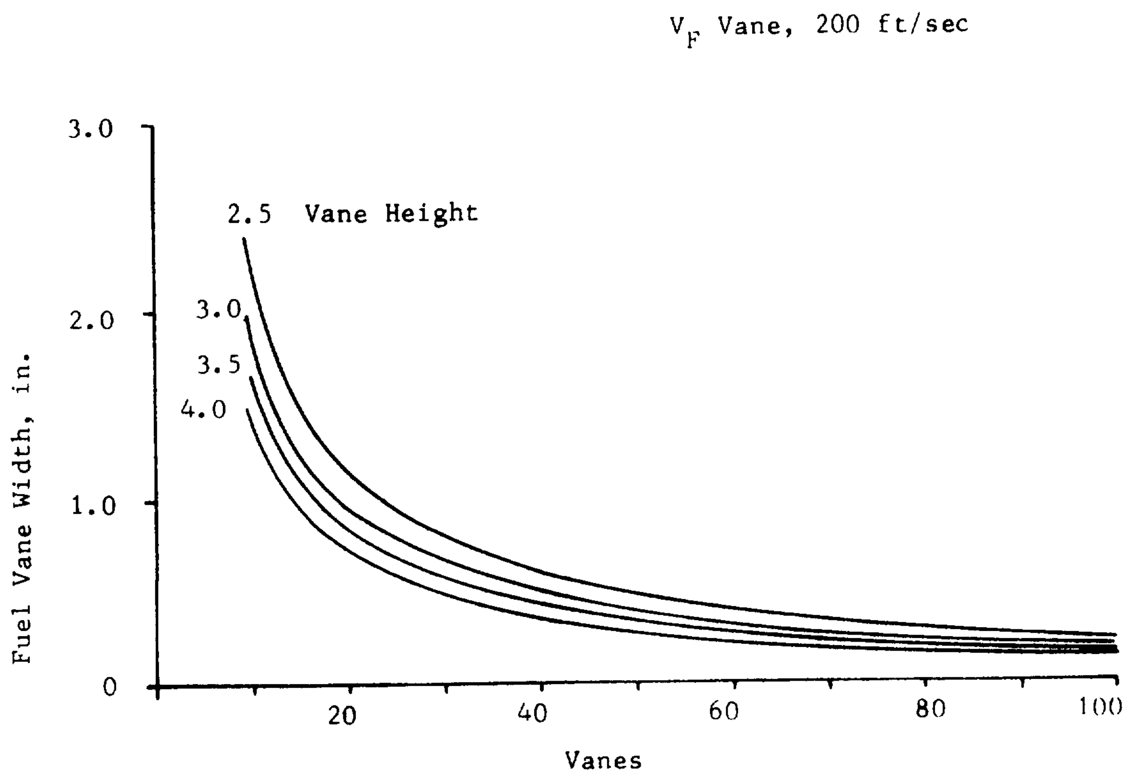


Figure III-6

EFFECT OF VANE QUANTITY AND HEIGHT ON OXYGEN INJECTION VELOCITY

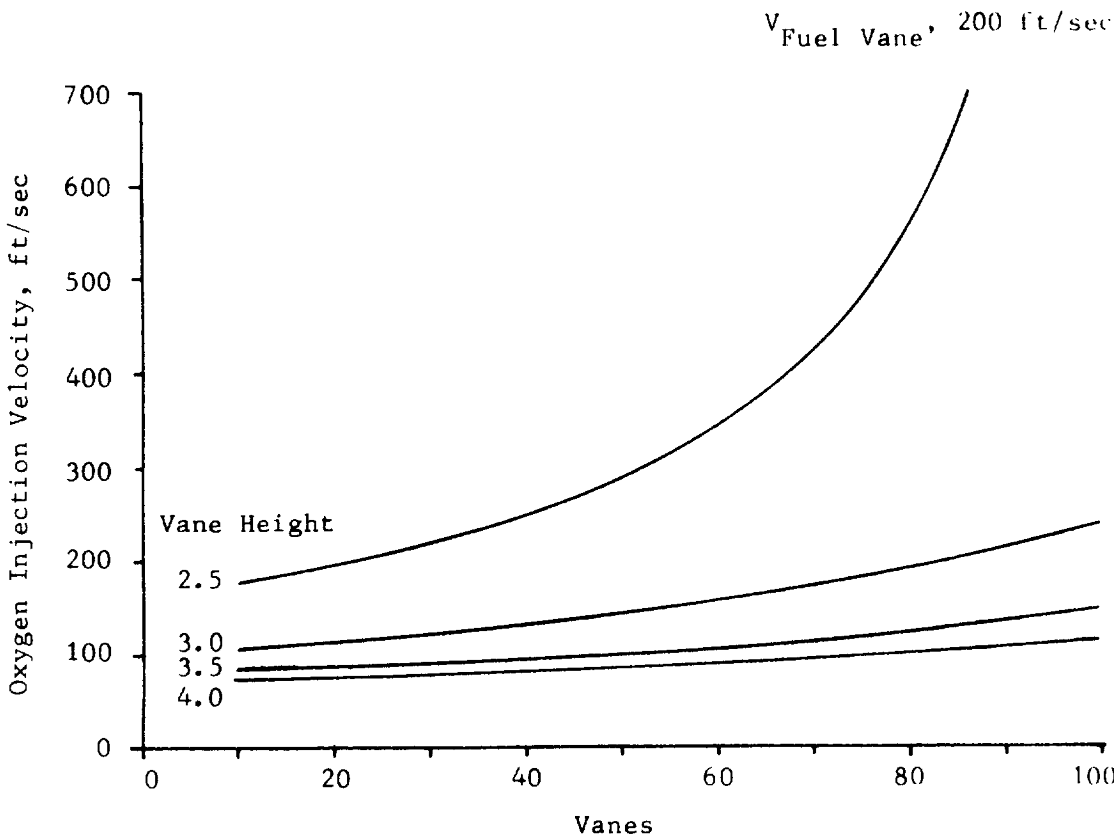


Figure III-7

EFFECT OF VANE QUANTITY AND HEIGHT ON
OXYGEN FLOW CHANNEL WIDTH

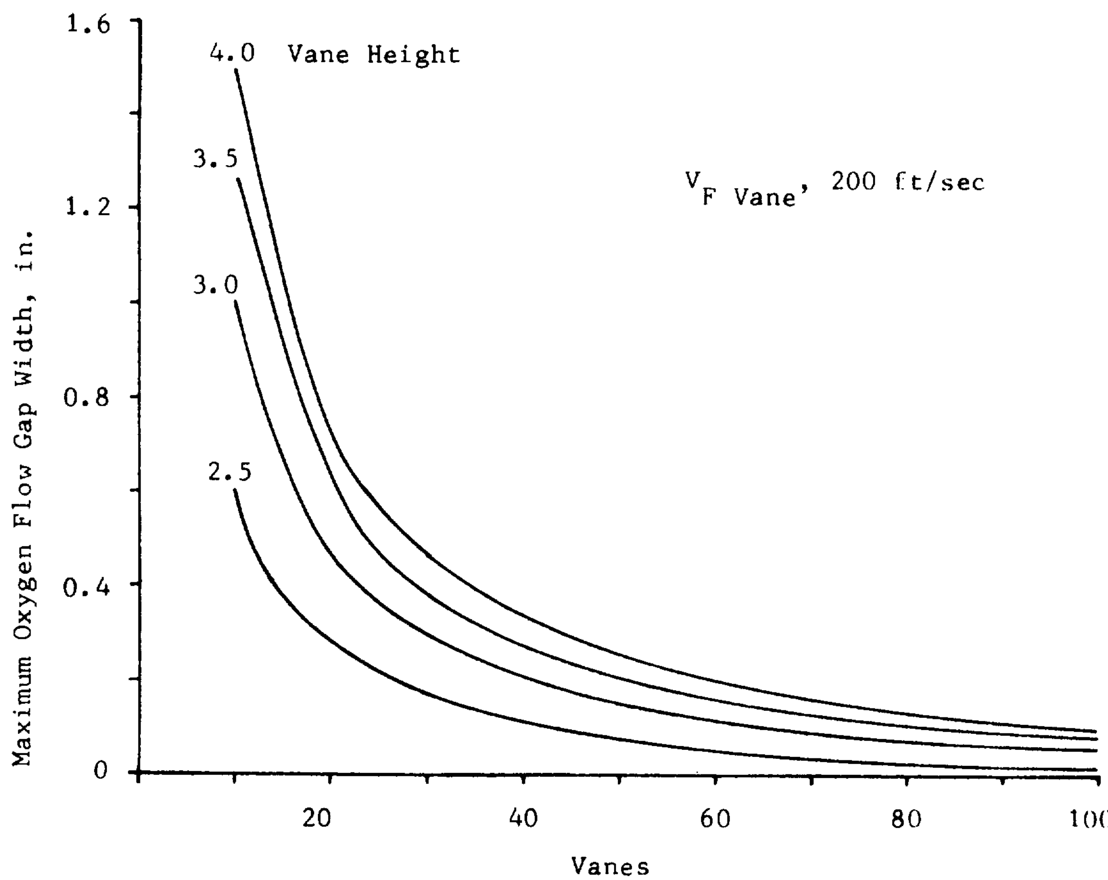


Figure III-8

III, A, Program Progress (Tasks XI Through XX) (cont.)

d. Cold Flow Model Design

Cold flow model design was delayed pending completion of the element quantity evaluation.

2. Task XII - Injector Fabrication

No injector fabrication scheduled during this activity.

3. Task XIII - Chamber Analysis and Design

Design of workhorse and streak chambers was initiated. These designs employ a nozzle section with match machined L* sections designed to minimize discontinuities which could disrupt the barrier coolant. Copper crush gaskets will be used to seal the chamber sections. Instrumentation of these components consists of barrier temperature probes, gas-side wall thermocouples, and a pressure tap.

Streak chambers will be provided by priming and then coating the inside of the nozzle and selected L* sections with Dow Corning 92-019 primer and 93-027 ablative. Pertinent features of these chamber designs are summarized below:

Geometric Features	
Contraction ratio	2 7
Expansion ratio	5.0
Expansion half angle	15 degrees

Injector Face to Throat Length, in.	L* of Combination, in.
6	10.4
8	15.8
12	26.6
16	37.4

III, A, Program Progress (Tasks XI Through XX) (cont.)

4. Task XIV - Thrust Chamber Fabrication

No activity scheduled.

5. Task XV - Ignition System Analysis and Design

Design of the catalytic igniter has been initiated and detail drawings which are in process are scheduled for completion early in the next report period. Pertinent features of this design are summarized below:

Type:	Catalyst bed pilot with secondary oxygen augmentation
Catalyst:	Shell 405, 14-18 mesh
Injector:	Brazed stainless steel with premix elements
Catalyst Bed:	1.26 dia by 0.5 to 0.75 in. long. Length variation capability to allow use of additional catalyst or an inert premix and distribution bed.
Propellant Flows:	Through catalyst - $\dot{w}_o$ = 0.00125 lb/sec $\dot{w}_f$ = 0.00125 lb/sec Augmenting oxygen - 0.06125 lb/sec Hydrogen coolant - 0.00115 lb/sec
Steady-State Effluent Temperature:	Through catalyst pack 2300°R (O/F 1.0) Secondary oxygen addition location will be varied for minimum chamber heating consistent with satisfactory engine ignition.
Predicted Response:	1.6 sec to 1250°F effluent temperature (expected reaction temperature with secondary oxygen)
Valves:	Futurecraft, 3/4 in. line size
Valve Sequencing:	To provide slight hydrogen lead and lag

III, A, Program Progress (Tasks XI Through XX) (cont.)

6. Task XVI - Ignition System Fabrication and Checkout

No activity scheduled.

7. Task XVII - Propellant Valves Preparation

Analysis and design of the propellant valves has been initiated. The design is based on the use of Titan II 5-in. butterfly valves with commercial actuators and pilot valves and a snubber to cushion the deceleration at the end of the travel.

Activities to date included a cursory examination of three candidate systems: pneumatic, hydraulic, and pneumatic/hydraulic design which uses pneumatics to shuttle a larger valve which in turn controls the hydraulic fluid flow to the thrust chamber valve actuators. The latter concept was eliminated because of potential problems of separating the gas and hydraulic fluids and preliminary design analyses which indicated the feasibility of the hydraulic or pneumatic systems.

Design and response analyses are being conducted for a single actuator piston size using two pilot valve flow areas and two operating pressures. Nominal design pressure is 1500 psi; however, system and component capability for over 2000 psi will be available if additional actuation force is needed. Both helium and hydraulic fluid are being evaluated.

The transient analysis will be completed early in the next report period. The control system installation layout is 75% complete. Upon completion of the transient analysis, snubber design, and the receipt of cost and delivery information for pilot valves, the layout will be submitted to the NASA/LeRC program manager for review and approval for the procurement of pilot valves prior to detail design.

III, A, Program Progress (Tasks XI Through XX) (cont.)

8. Tasks XVII Through XX

No activity scheduled.

B. CURRENT PROBLEMS

No significant technical or scheduling problems are foreseen at this time.

C. WORK TO BE PERFORMED IN NEXT REPORT PERIOD

Task XI

1. Conclude selection of exact coaxial element size.
2. Complete cold flow model designs for coaxial and vaned injectors.
3. Initiate detailed injection element design.

Task XII

Fabricate element cold flow models.

Task XIII

Submit chamber designs for approval prior to fabrication.

Task XIV

Initiate fabrication of workhorse chambers.

Task XV

Complete the design of the catalytic igniter and submit for approval.

Task XVI

Initiate fabrication and prepare and submit a checkout test plan for the catalytic igniter.

III, C, Work to be Performed in Next Report Period (cont.)

Task XVII

Complete analysis and detail design of the propellant valves, submit for approval, and initiate fabrication.

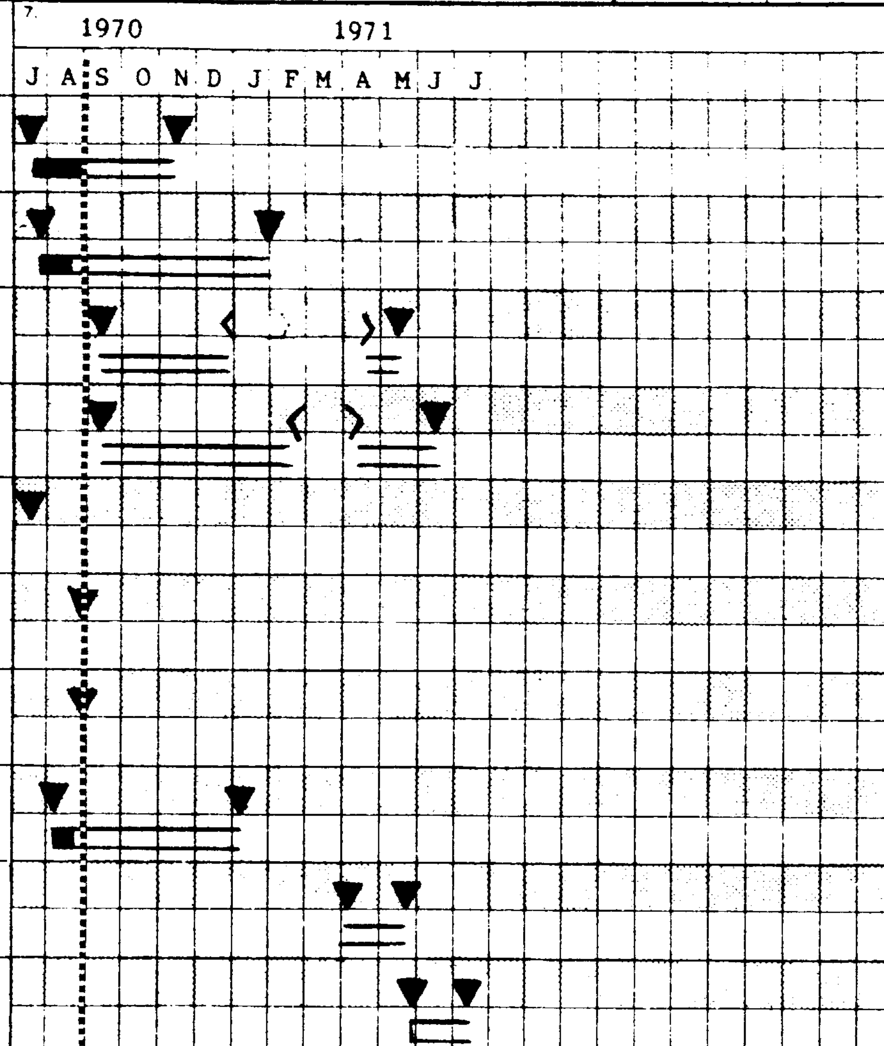
Task XVIII

Prepare and submit and submit an element cold flow test plan for approval. Initiate cold flow testing.

Tasks XIX and XX

No activity planned.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Lewis Research Center	**CONTRACT PROGRESS SCHEDULE**	REPORT FOR MONTH ENDING 31 Aug 1970	FORM APPROVED BUDGET BUREAU NO. 104-R0007	9. NASA Use Only a. NASA CODE
1. CONTRACT TITLE Hydrogen-Oxygen APS Engines (Hi P_c)	2. CONTRACTOR (Name and address) Aerojet Liquid Rocket Co., P.O. Box 15847 Sacramento, California 95813		3. CONTRACT NO. NAS 3-14354	b. PROJECT MGR
	4. APPROVED (Contractor's Project Manager) L Schoenman	PREPARATION DATE 9-10-70	5. NASA APPROVED SCHEDULE DATE 8-31-70	c. EVALUATION DATE
				d. EXCEPTION CATEGORY



6. REPORTING CATEGORY	8. TECH. OBJECTIVE % COMP	e.	f.	g.
Injector Analysis and Design	75			
Injector Fabrication	5			
Thrust Chamber Analysis and Design				
Thrust Chamber Fabrication				
Ignition System Analysis and Design				
Ignition System Fabrication and Checkout				
Bipropellant Valve Preparation				
Injector Tests				
Thrust Chamber Cooling Tests				
Pulsing Tests				

NASA-C-63 (Rev. 1-68)

NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lewis Research Center

CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 31 Aug 1970

FORM APPROVED BUDGET BUREAU NO. 104-R0037

1. CONTRACT TITLE: Hydrogen-Oxygen APS Engines (Low P_c)

2. CONTRACTOR (Name and address): Aerojet Liquid Rocket Co., P.O. Box 15847, Sacramento, California 95813

3. CONTRACT NO.: Amendment I NAS 3-1-35-

4. APPROVED (Contractor's Project Manager): [signature]

PREPARATION DATE: 9-9-70

5. NASA APPROVED SCHEDULE DATE: 8-31-70

6. NASA Use Only
a. NASA CODE
b. PROJECT MGR
c. EVALUATION DATE
d. EXCEPTION CATEGORY

6. REPORTING CATEGORY	7. 1970: A S O N D — 1971: J F M A M J J A S	8. TECH. OBJECTIVE % COMP.	e.	f.	g.
Injector Analysis and Design		5			
Injector Fabrication		0			
Thrust Chamber Analysis and Design		5			
Thrust Chamber Fabrication		0			
Ignition System Analysis and Design		60			
Ignition System Fabrication and Checkout		0			
Bipropellant Valves Preparation		15			
Injector Tests		0			
Thrust Chamber Cooling Tests		0			
Pulsing Tests		0			

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NASA APPROVED SCHEDULE

CONTRACTOR'S WORKING SCHEDULE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lewis Research Center

CONTRACT PROGRESS SCHEDULE

REPORT FOR MONTH ENDING: 31 Aug 1970

FORM APPROVED
BUDGET BUREAU NO. 104-R0007

9. NASA Use Only
a. NASA CODE
b. PROJECT MGR
c. EVALUATION DATE
d. EXCEPTION CATEGORY

1. CONTRACT TITLE: Hydrogen-Oxygen APS Engines

2. CONTRACTOR (Name and address): Aerojet Liquid Rocket Co., P.O. Box 15847 Sacramento, Calif 95813

3. CONTRACT NO: NAS 3-14354

4. APPROVED (Contractor's Project Manager): L Stevenson R. J. [illegible]

PREPARATION DATE: 9-9-70

5. NASA APPROVED SCHEDULE DATE: 8-31-70

6. REPORTING CATEGORY	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	8. TECH. OBJECTIVE % COMP.	e.	f.	g.
Program Plan and Test Plans High P_c	▽	▽							▽		▽					25			
Low P_c		▽▽		▽	▽					▽		▽				16			
Monthly Reports	▽	▽		▽	▽		▽	▽		▽	▽		▽			22			
Quarterly Reports			▽			▽			▽			▽				0			
Final Report Draft													▽		▽	0			

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NASA APPROVED SCHEDULE
CONTRACTOR'S WORKING SCHEDULE